

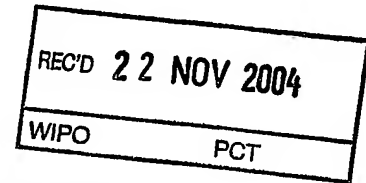


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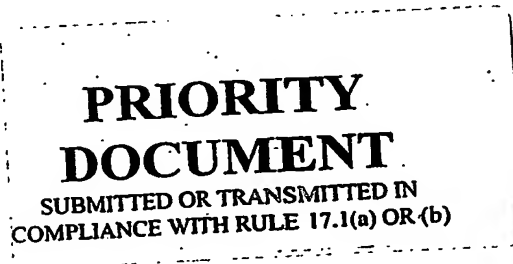
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Patentanmeldung Nr. Patent application No. Demande de brevet n°

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Der Präsident des Europäischen Patentamts;  
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets  
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(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.  
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Method and apparatus for reducing metal-oxygen compounds

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## METHOD AND APPARATUS FOR REDUCING METAL-OXYGEN COMPOUNDS

The present invention relates to a method for reducing metal-oxygen compounds with carbon as an agent for reducing the metal-oxygen compounds. The invention also relates to an apparatus for reducing metal-oxygen compounds with carbon as an agent for reducing the metal-oxygen compounds.

Reduction of metal-oxygen compounds, such as metal-oxides, for instance iron oxides, has been performed in large-scale reduction furnaces. For the reduction of iron-oxygen compounds, the blast furnace has been the workhorse for the production of pig iron from iron ore for over a century. The primary reductant and source of chemical energy in these blast furnaces is coke. Coke is produced by baking coal in the absence of oxygen in order to remove the volatile hydrocarbons and to give the coke the critical properties for stable blast furnace operation.

Coke making is problematic from an environmental perspective as many of the volatile hydrocarbons are hazardous. Also not all types of coal are suitable for coke making. Moreover, demand has decreased for the by-products of coke making.

Therefore, decreasing the coke rate and the over-all fuel rate of the blast furnace has been a major focus of recent developments. Also new technologies to circumvent the blast furnace process, such as direct reduction of iron ore, have been developed.

Direct reduction involves the production of iron by reduction of iron ore with a reducing agent, which can be a solid reducing agent, or a gaseous reducing agent. The directly used solid reducing agents are coals of any size, instead of coke. Examples of reducing gasses are natural gas, hydrogen or carbon monoxide. Ores for direct reduction have to meet stringent specifications with high percentage of Fe and low content of unwanted elements.

Direct reduction of iron ore may produce a solid direct-reduced iron product or, at high operating temperatures or in combination with a smelting device, a liquid product.

The product of a direct reduction process could be discharged in a second reactor for melting and optional further refining, or cooled and stored for later use.

At present, iron-rich dust and sludge from an integrated steelworks is recycled as raw material in the ore preparation stage. However, due to the high content of metals such as zinc in these waste materials, often referred to as 'fines', the accumulation of such elements, and the limitations of the amount of these metals for charging into a blast furnace, these waste materials have often to be recycled in an other way or disposed of,

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resulting in additional costs or burdening of the environment. It is known that direct reduction processes can be used to recycle the aforementioned waste materials.

A known process for reduction of iron ore is based on the direct reaction of coal and lump iron ore or pellets in a rotary kiln. Another known process is based on the reduction  
5 of composite pellets containing iron oxide and carbon from for example coal, coke or charcoal in a rotary hearth furnace. The off-gasses from the reduction reaction can be post combusted in the furnace to provide a portion of the heat required for the process. Another known process involves direct reduction of fine iron ore in a fluidised bed reactor.

A major disadvantage of these known reduction processes is that they operate at  
10 high temperatures. Furthermore, if these processes are based upon the use of coal, a further disadvantage is the development of large volumes of carbon monoxide, hydrogen and hydrocarbons. Condensation of these complex and hazardous hydrocarbons must be avoided which requires removal or post-combustion of the off gasses while re-oxidation of the metal by the oxidising off gases must be prevented. Also, because of the high  
15 operating temperatures and consequent heat losses, and the generation of large amounts of carbon monoxide, the energy efficiency of the direct reduction processes is generally poor resulting in a high carbon consumption rate. The high operating temperatures also result in the formation of significant amounts of harmful nitrogen-oxygen compounds (NOx-gases). Furthermore, technologies that use coal directly have to deal with higher  
20 levels of sulphur because of the presence of sulphur in the coal.

It is an object of the invention to provide a method and an apparatus for reducing metal-oxygen compounds which operates at low temperatures.

It is a further object of this invention to provide a method and an apparatus for reducing metal-oxygen compounds which produces lower volumes of hazardous off gases  
25 such as for example hydrocarbons and/or NOx-gases.

It is also an object of the invention to provide a method and an apparatus for reducing metal-oxygen compounds, which results in an increased carbon efficiency per unit of weight of reduced metal.

It is also an object of the invention to provide a method and an apparatus for  
30 reducing metal-oxygen compounds, which has an improved energy efficiency and provides a product with a low sulphur content.

It is a further object of the invention to provide a method and an apparatus for reducing a mixture of different metal-oxygen compounds, which results in a metal alloy.

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To achieve one or more of these objects a method is provided for reducing metal-oxygen compounds in which carbon is used as a reducing agent in a reduction reaction for reducing the metal-oxygen compounds wherein a first metal is used to aid the reduction reaction. This first metal performs the role associated with a catalyst.

5 It was surprisingly found that the addition of a first metal greatly enhances the reduction rate of the metal-oxygen in which carbon is used as a reducing agent for reducing the metal-oxygen compounds. It was also found that this reduction takes place at significantly lower temperatures in comparison to the known types of direct reduction processes. For example, the known types for reduction of iron-oxygen compounds  
10 employ operating temperatures of over 950 °C. The lower operating temperature of the process according to the invention will also result in lower output of harmful nitrogen-oxygen compounds as well as in a reduced heat loss of the installations.

In a preferred embodiment the carbon, which is used as a reducing agent for reducing the metal-oxygen compounds, is amorphous carbon and/or crystalline carbon,  
15 preferably graphite, because the reaction rate of the reduction reaction is considerably increased. Boudouard-carbon as a species of crystalline carbon, or graphite in particular, proved to be a preferred form of carbon. Since increasing the number of contact points between reactants also enhances the reaction rate, it is preferred that the carbon, which is used as an agent for reducing the metal-oxygen compounds, is in the form of a powder.

20 The first metal for the reduction reaction of the metal-oxygen compounds can be added to the metal-oxygen compounds at any stage of the process provided the first metal is at least present at the time the reduction of the metal-oxygen compounds should occur.

In a further preferred embodiment of the invention for reducing metal-oxygen  
25 compounds, in which carbon is used as a reducing agent for reducing the metal-oxygen compounds, carbon monoxide is brought into contact with the metal-oxygen compounds and carbon is formed by the Boudouard reaction from the carbon monoxide with the aid of a second metal. This carbon is referred to as Boudouard-carbon. The carbon monoxide may be substantially pure carbon monoxide, but it may also be part of a gaseous mixture  
30 comprising carbon monoxide. During start-up of the process of reducing the metal-oxygen compounds, but also during the process of reducing the metal-oxygen compounds, compounds similar to Boudouard-carbon and in a suitable form, such as graphite powder, may be added to the metal-oxygen compounds to serve as the reducing agent for at least

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part of the reduction of the metal-oxygen compounds. The second metal performs the role associated with a catalyst.

Surprisingly, it has been found that the Boudouard-carbon which is generated by dissociation of carbon-monoxide by the Boudouard reaction:



is a reducing agent which, in combination with a first metal, very effectively reduces the metal-oxygen compounds when the Boudouard-carbon, the first metal and the metal-oxygen compound are brought into contact at a predetermined elevated temperature.

Surprisingly it was found that the first metal not only aids the reduction of the metal-oxygen compounds, but it may also have a beneficial effect on the formation of the Boudouard-carbon by the Boudouard reaction. The first metal may be added to the process either at the start of the process or during the process, but some of it may also be formed by the reduction of the metal-oxygen compounds already occurring at the lower temperature at which the Boudouard reaction is performed.

15        Since the gaseous reaction products of the process according to the invention comprise a high level of carbon-dioxide gas in comparison to the off-gases of the conventional processes, the carbon is efficiently used, thereby also reducing the amount of used fossil fuel. The amount of carbon used per unit of weight of reduced metal is consequently lower in the process according to the invention.

20        Also, since no coal is used directly in the process, the gaseous reaction products of the process according to the invention do not contain the coal-related hazardous hydrocarbons and the sulphur content of the reacting solids is not affected.

In a further embodiment of the invention the first metal is the same as the second metal, thereby introducing to as low an amount as possible other metals to the products of the reduction reaction for reducing the metal-oxygen compounds. In still a further embodiment of the invention the first and/or second metal is the same as the metal in the metal-oxygen compounds. When producing a single metal material the amount of other elements is to be kept as low as possible to prevent contamination with other metals. When producing an alloy, it may be advantageous to use one or more metals as a first and/or second metal that are different from the metal in the metal-oxygen compound.

30        In a preferred embodiment of the invention the reduction reaction of the metal-oxygen compounds is performed in a continuous process. In a further preferred embodiment the carbon monoxide moves relative to the mixture of the metal-oxygen

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compounds, the reducing agent for the reduction of the metal-oxygen compounds and the first and/or second metal. In a further preferred embodiment, the metal-oxygen compounds are transported in one direction and the carbon monoxide is transported in another direction. In a further preferred embodiment the metal-oxygen compounds and the carbon monoxide are transported in counter flow. Also, at least part of the gaseous reaction products may be reintroduced into the process, thereby reducing the amount of fresh carbon monoxide that is to be added. Moreover, at least part of the substantially solid product of the reduction reaction of the metal-oxygen compounds may be reintroduced into the process as a first and/or second metal for the reduction reactions, thereby reducing the amount of fresh first and/or second metal that is to be added.

For reasons of reaction kinetics the operating temperature in the first reaction region where the Boudouard reaction is performed is preferably below 650 °C, preferably between 300 and 600 °C and more preferably between 450 and 550 °C. In a preferred embodiment of the invention the metal-oxygen compounds comprise iron-oxygen compounds such as iron oxide and/or iron hydroxide and/or iron-carbonate and/or iron ore. Also the first and/or second metal may comprise iron thereby limiting the amount of non-iron metals in the resulting product of the reduction reaction of the iron-oxygen compounds. For reasons of reaction kinetics the operating temperature in the reaction region where the reduction of the metal-oxygen compounds is performed is preferably between 550 and 900 °C, preferably between 650 and 850 °C, and more preferably between 700 and 775 °C. The process according to the invention as described hereinabove is performed essentially at atmospheric pressures. It is obvious for the skilled person that performing the method according to the invention at non-atmospheric pressures will shift the balance of the reactions accordingly. The invention also encompasses performing the method at sub atmospheric or super atmospheric pressures, and it also encompasses using the method according to the invention in such a way that the Boudouard reaction occurs at a different pressure than the reduction of the metal-oxygen compounds.

It should be noted that due to the nature of the Boudouard reaction and the reduction of the metal-oxygen compounds in terms of kinetics there may be an overlap between the reaction region where the carbon is formed from the carbon monoxide by the Boudouard reaction and the reaction region where the reduction reaction of the metal-oxygen compounds is performed mainly occurs insofar as some Boudouard carbon may

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still be formed in the reaction region where the reduction of reaction of the metal-oxygen compounds is performed and insofar as some metal-oxygen compounds may at least partly already have been reduced in the reaction region where the Boudouard reaction is performed, thereby providing at least part of a first metal for the reduction reactions.

5        Since the number of contact points between the reducing agent, the first metal and the metal-oxygen compound determines the kinetics of the reduction process of the metal-oxygen compound by the process according to the invention, it is preferable that the metal-oxygen compound and the first metal are in the form of a powder. The grain size of these powders should preferably be below 1 mm, but more preferably be 100 µm  
10    or lower. These powders or mixtures thereof may be pre-treated to form conglomerates such as pellets or sinter, which have a sufficient porosity for the carbon monoxide to access the first metal and the metal-oxygen compound in the conglomerate. Although the process according to the invention already works when small amounts of a first metal are present, it has been found that the amount of first metal should preferably be higher than  
15    1% in weight of the metal-oxygen compounds, more preferably be higher than 5% in weight and preferably be about 10% in weight at the beginning of the phase in the process where the reduction of the metal-oxygen compounds is performed.

The invention also relates to a method wherein the reduction reaction is performed in a shaft furnace, such as a blast furnace. The invention is also embodied in a method  
20    wherein the metal-oxygen compounds comprise iron-oxygen-compounds and wherein the reduction reaction of the iron-oxygen compounds is performed in a shaft furnace, such as a blast furnace, to produce iron. It was found that application of the process according to the invention in the conventional blast furnace process involving the addition of iron as a first metal for the reduction reaction of iron ore results in a disproportionate increase of  
25    molten iron. For instance the addition of the iron as a first metal, for example in the form of a powder, to iron ore to form a mixture to produce conventional pellets therefrom, may supply the mixture of iron-oxygen compounds and iron as a first metal which enter the blast furnace process. During the course of the blast furnace process the pellets descend into the furnace and at the proper temperature the first generation of Boudouard carbon  
30    will start using the carbon monoxide gas which evolves from the burning coke in the lower regions of the blast furnace. The carbon monoxide gas is reduced to carbon dioxide gas and Boudouard carbon. This carbon is believed to precipitate on the mixture of iron-oxygen compound and iron as a first metal and the combined materials descend further



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into the blast furnace. At the proper temperature the reduction of the iron-oxygen compounds will start, thereby reducing the iron-oxygen compound to iron. Ultimately, after descending even further into the blast furnace, the iron will melt and be ready for tapping from the blast furnace by known methods. It is obvious that the method according to the

5 invention also works when the iron ore and the first metal, which may be iron, are added to the process in the form of a sintered product or any other conglomerate with a large contact area between the iron-ore, the first metal, and the carbon monoxide. As a result of the invention, the carbon-monoxide output of the blast-furnace process will be reduced due to the more efficient use of the carbon from the coke, and the output of molten iron

10 from the blast furnace per time unit will increase disproportionally with regard to the added iron catalyst. In other words, the amount of molten iron per time unit than can be tapped from the furnace after the addition of x% of iron as a first metal per time unit to the iron-ore will result in more than 100+x% of molten iron per time unit which can be tapped, thereby making a more efficient use of the blast furnace by increasing the amount of

15 newly formed iron from the iron-ore per time unit. Obviously, the usage of iron-ore per time unit has to be increased correspondingly.

Comparable application of the method and comparable increases in productivity may be achieved in any conventional DRI-facility where metal ore, which may for example be sintered or be in the form of pellets, is processed. These DRI-facilities conventionally

20 comprise at least one furnace where the reduction of the metal-oxygen compounds takes place wherein the furnace are for instance chosen from the group of furnaces comprising rotary hearth furnaces, rotary kiln furnaces, shaft furnaces, cyclone furnaces, continuous batch-type furnaces. The invention is therefore also embodied in a method wherein the reduction reaction of the metal-oxygen compounds is performed in a fluidised bed, a

25 rotary hearth furnace, a rotary kiln furnace, a cyclone furnace, or a continuous batch-type furnace, to produce directly reduced metal. The invention is further also embodied in a method wherein the metal-oxygen compounds comprise iron-oxygen-compounds and in that the reduction process of the iron-oxygen compounds is performed in a fluidised bed, a rotary hearth furnace, a rotary kiln furnace, a cyclone furnace, or a continuous batch-

30 type furnace.

The invention is also embodied in a method for reducing metal-oxygen compounds to produce a substantially solid material comprising a metallic part and a non-metallic part wherein the substantially solid material is treated to separate the metallic part from a non-

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metallic part such as gangue or slag. This separation step may be performed for instance in a cyclone.

5 The invention is also embodied in a method wherein the metallic part is compressed to reduce its porosity. The metallic part may also be rolled to form a slab, billet, bloom, rod, section or strip. This method enables omitting a step in the production process starting from ore and ending with slab, thereby significantly reducing costs and energy consumption. The metallic part may also be extruded to form a profile, section or rod, or be formed into a near net shape product. These products will require no, or only limited final processing.

10 The metallic part may also be used as feed material in a smelting operation, for instance using an Electric Arc Furnace or, in case of iron, as feed material in a steelmaking process at least as a partial replacement of scrap in for instance an Basic Oxygen Steelmaking process or a Siemens Martin Steelmaking process.

15 It should be noted that the invention also relates to a method wherein the metal in the metal-oxygen compound(s) is copper, cobalt, nickel, ruthenium, rhodium, palladium, platinum or iridium. It should be noted that for some metals more than one metal-oxygen compound exists, e.g. copper-oxide and copper-hydroxide. The invention also relates to a method wherein the metal-oxygen compounds comprises a mixture of at least two metal-oxygen compounds, wherein the metals in the metal-oxygen compounds are different and  
20 wherein the metals comprise Iron, Copper, Cobalt, Nickel, Ruthenium, Rhodium, Palladium, Platinum or Iridium, thereby producing a reduced product comprising at least two different metals. The advantage of this embodiment is that an alloy may be produced directly. The first metal or first metals may also be different from the metal or metals in the metal-oxygen compound.

25 A gaseous mixture comprising the carbon-monoxide, from which the carbon is to be formed by the Boudouard reaction, may be produced by treating in a standard gasifier according to a known process at least one carbon-containing compound which is chosen from a group of carbon-containing compounds comprising cokes, coal, charcoal, oil, plastics, natural gas, paper or biomass. Undesired elements like for instance sulphur may  
30 be removed from the gaseous mixture by an appropriate pre-treatment. The standard gasifier may be equipped with means to control the output of hazardous or unwanted by-products, which result from the gasification of the carbon-containing compound.

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The invention also relates to an apparatus for reducing metal-oxygen compounds in a reduction reaction characterised in that it comprises a reactor, an inlet for the metal-oxygen compounds and optionally the first and/or second metal, an inlet for a gaseous mixture comprising carbon-monoxide, optional heating or cooling means to heat or cool the different parts of the reactor, an outlet for the gaseous reaction products and an outlet for the substantially solid material resulting from the reduction of the metal-oxygen compounds.

In a further embodiment of the invention a reactor is used comprising a first reaction region and a second reaction region. In the first reaction region, nearer to the inlet for the metal-oxygen compounds, carbon is formed from the carbon monoxide by the Boudouard reaction as a result of the choice of operating parameters such as temperature and pressure, and in the second reaction region, nearer to the outlet of the substantially solid material resulting from the reduction of the metal-oxygen compounds, the metal-oxygen compounds are reduced as a result of the choice of operating parameters such as temperature and pressure. Generally, at similar operating pressures, the temperature of the first reaction region is lower than the temperature of the second reaction region.

In a preferred embodiment the reactor also comprises transportation means to transport the substantially solid reactants. It should be noted that in the abovementioned embodiment, the first and/or second metal is added at the start of the process. It is obvious from the above that the first and/or second metal optionally can also be added in a later or earlier stage of the process, thereby requiring an optional additional inlet. Also, during start-up of the process, but also during the process, compounds similar to Boudouard-carbon and in a suitable form, such as graphite powder, may be added to the metal-oxygen compounds to serve as the reducing agent in the reduction reaction of the metal-oxygen compounds, thereby optionally requiring one or more additional inlets for the carbon.

In a further embodiment according to the invention, the reactor also comprises means to reintroduce at least part of gaseous reaction products into the process. Moreover, the reactor may also comprise means to reintroduce at least part of substantially solid material resulting from the reduction of the metal-oxygen compounds into the process.

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In a further embodiment these reactor regions may be physically separated to occur in separate reactors, enabling a more independent choice of operating parameters such as temperature and pressure.

5 In a further embodiment the reactor includes a fluidised bed. In still a further embodiment the reactor comprises a furnace chosen from the group of furnaces comprising rotary hearth furnaces, rotary kiln furnaces, shaft furnaces, cyclone furnaces, continuous batch-type furnaces.

In a preferred embodiment, the reactor has a substantially tubular, more preferably a substantially axi-symmetrical shape.

10 A specific embodiment of the present invention will now be explained by the following non-limitative examples and described with reference to the schematic drawing of which:

Fig. 1 shows schematically a device according to the invention.

15 Fig. 2 shows schematically a preferred embodiment of a device according to the invention.

Fig. 3 shows schematically a preferred embodiment of a device according to the invention with separated reaction regions.

20 In Fig. 1 the invention is embodied in an apparatus for reducing metal-oxygen compounds according wherein the apparatus comprises a reactor 1, an inlet 2 for the metal-oxygen compounds, an inlet for the first and/or second metal (not shown, unless the first and/or second metal is added together with the metal-oxygen compounds, in which case the first and/or second metal inlet is 2 as well), an inlet 3 for a gaseous mixture comprising carbon-monoxide, heating means to heat the different parts of the reactor (not shown), an outlet 4 for the gaseous reaction products and an outlet 5 for the  
25 substantially solid material resulting from the reduction of the metal-oxygen compounds.

30 In Fig. 2 another embodiment of the invention is shown wherein the apparatus comprises a reactor 1, an inlet 2 for the metal-oxygen compounds, an inlet for the first and/or second metal (not shown, unless the first and/or second metal is added together with the metal-oxygen compounds, in which case the first and/or second metal inlet is 2 as well), an inlet 3 for a gaseous mixture comprising carbon-monoxide, heating or cooling means to heat or cool the different parts of the reactor (not shown), an outlet 4 for the gaseous reaction products and an outlet 5 for the substantially solid material resulting from the reduction of the metal-oxygen compounds, transportation means 6 to transport

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the solid reactants, means 7 to reintroduce at least part of gaseous reaction products from outlet 4 into the process, and means 8 to reintroduce at least part of substantially solid material resulting from the reduction of the metal-oxygen compounds.

5 In Fig. 3 another embodiment of the invention is shown wherein the reactor comprises a first reactor part 9 where the generation of carbon by the Boudouard mainly occurs, a second reactor part 10 where the reduction of the metal-oxygen compounds mainly occurs, transport means 11 to transport the solid reactants from the first reactor part 9 to the second reactor part 10, transport means 11 to transport the gaseous mixture comprising carbon-monoxide from the second reactor part 10 to the first reactor part 9, an  
10 inlet 2 for the metal-oxygen compounds, an inlet for the first and/or second metal (not shown, unless the first and/or second metal is added together with the metal-oxygen compounds, in which case the first and/or second metal inlet is 2 as well), an inlet 3 for a gaseous mixture comprising carbon-monoxide, heating or cooling means to heat or cool the different parts of the reactor (not shown), an outlet 4 for the gaseous reaction  
15 products and an outlet 5 for the substantially solid material resulting from the reduction of the metal-oxygen compounds. This embodiment may also be equipped with means to reintroduce at least part of the gaseous reaction products from outlet 4 into the process, and means to reintroduce at least part of the substantially solid material resulting from the reduction of the metal-oxygen compounds as a first and/or second metal into the process  
20 through the catalyst inlet, but these are not shown in Fig. 3.

One or more optional inlets may be present in all three embodiments for the introduction of compounds similar to Boudouard-carbon and in a suitable form, such as graphite powder during start-up of the process and/or during the process.

#### 25 Example 1

In a thermal gravimetry analyser a homogeneous mixture of iron oxide as the metal-oxygen compound, carbon as the reducing agent for reducing the metal-oxygen compound and iron as the first and second metal, was heated. The amount of carbon was chosen to be sufficient to enable a complete reduction of the iron oxide to metallic iron.  
30 The reduction in mass of the mixture forms a direct indication of the reduction of the metal-oxygen compound. In case of a complete reduction, a reduction of mass of about 12-15% is to be expected. These measurements showed that at temperatures between 650 and 850 °C a complete reduction of the iron oxide was achieved when powder of

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crystalline carbon such as crystalline graphite, synthetic graphite, elektrographite or Boudouard-carbon was used. Powder coal, activated carbon or powder coke proved to be less effective insofar that the iron oxide was not or only partly reduced to iron below 900 °C. The activity of amorphous carbon for the reduction of the iron oxide proved to be lower than the activity of crystalline carbon such as graphite, but higher than the activity of powder coal, activated carbon or powder coke.

#### Example 2

In a reactor, comprising a stainless steel tube and a furnace, an extruder type screw was mounted as transportation means for solid reactants. A mixture of iron oxide, carbon similar to Boudouard-carbon and in a suitable form, and iron powder as a first metal, was introduced in the tube and brought to a temperature of between 650 °C and 850 °C. The iron oxide reduced to metallic iron quickly.

#### Example 3

In a reactor according to Figure 2, wherein a stainless steel tube forms the reactor, an extruder type screw was mounted as transportation means 6 for the solid reactants. The arrow indicates the transportation direction of the solid reactants. A mixture of iron oxide as the metal-oxygen compound and iron powder as a first metal was introduced through inlet 2 at one end of the tube and transported to the other end of the tube by the extruder screw 6. In counter flow, a hot gaseous mixture comprising carbon monoxide was introduced into the reactor through inlet 3, also providing the heat for the reduction reactions in the reactor. The temperature of the reactants at the entry of the gaseous mixture was about 900 °C and the temperature at the exit of the gaseous mixture of the solid reactants was about 550 °C. At the cool end of the reactor, in the first reaction region, Boudouard-carbon was formed from the carbon monoxide by the Boudouard reaction with the aid of the metallic iron which performs the role associated with a catalyst. The resulting carbon dioxide leaves the process through outlet 4 as a part of the gaseous reaction products. The Boudouard-carbon precipitated on the solid reactants and was transported by the extruder screw to the second reaction region together with the solid reactants. In said second reaction region the iron oxide is reduced by the Boudouard carbon resulting in metallic iron and a mixture of carbon monoxide and carbon dioxide. Part of the substantially solid iron may be reintroduced into the process by means 8 as a

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first metal through for example inlet 2 and part of the gaseous reaction products may be reintroduced by means 7 through for example inlet 3.

It is of course to be understood that the present invention is not limited to the embodiments and examples described above, but encompasses any and all  
5 embodiments within the scope of the claims and the description.

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**CLAIMS**

1. Method for reducing metal-oxygen compounds in which carbon is used as a reducing agent in a reduction reaction for reducing the metal-oxygen compounds characterised in that a first metal is used to aid the reduction reaction.  
5
2. Method according to claim 1 characterised in that the carbon is amorphous carbon and/or crystalline carbon, preferably graphite.
- 10 3. Method according to claims 1 or 2 characterised in that the carbon is in the form of a powder.
4. Method according to any of the claims 1-3 characterised in that carbon monoxide is brought into contact with the metal-oxygen compounds and that carbon is formed by the Boudouard reaction from the carbon monoxide with the aid of a second metal.  
15
5. Method according to any of the claims 1-4 characterised in that the first metal is the same as the second metal.
- 20 6. Method according to any of the claims 1-5 characterised in that the first and/or the second metal is the same as the metal in the metal-oxygen compounds.
7. Method according to any of the claims 1-6 characterised in that the metal-oxygen compounds are in the form of a powder.  
25
8. Method according to any of the claims 1-7 characterised in that the first and/or the second metal is in the form of a powder.
9. Method according to claim 7 or 8 characterised in that a mixture of powders of the first and/or second metal and metal-oxygen compounds is used in the form of a conglomerate, such as a pellet or sinter.  
30



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10. Method according to any of the claims 1-9 characterised in that the reduction reaction of the metal-oxygen compounds is performed in a continuous process.
- 5 11. Method according to claim 10 characterised in that the metal-oxygen compounds are transported in one direction and in that the carbon monoxide is transported in counter flow.
- 10 12. Method according to claim 10 or 11 characterised in that at least part of substantially solid products of the reduction reaction is reintroduced into the process.
13. Method according to any of the claims 10-12 characterised in that at least part of gaseous reaction products is reintroduced into the process.
- 15 14. Method according to any of the claims 4-13 characterised in that the temperature where the Boudouard reaction is performed is below 650°C, more preferably between 300 and 600 °C, an even more preferably between 450 and 550 °C.
- 20 15. Method according to any of the claims 1-14 characterised in that the metal-oxygen compounds comprise iron-oxygen compounds, such as iron oxide and/or iron-hydroxide and/or iron-carbonate.
- 25 16. Method according to any of the claims 1-15 characterised in that the first metal and/or the second metal comprises iron.
- 30 17. Method according to claim 15 or 16 characterised in that the temperature where the reduction of the metal-oxygen compounds is performed is between 550 and 900°C, more preferably between 650 and 850 °C, and even more preferably between 700 and 775 °C.
18. Method according to any of the claims 1-14 characterised in that the metal in the metal-oxygen compound(s) is Copper, Cobalt, Nickel, Ruthenium, Rhodium, Palladium, Platinum or Iridium.

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19. Method for reducing metal-oxygen compounds according to any of the claims 1 to 18 characterised in that the metal-oxygen compounds comprises a mixture of at least two metal-oxygen compounds, wherein the metals in the metal-oxygen compounds are different and wherein the metals comprise Iron, Copper, Cobalt, Nickel, Ruthenium, Rhodium, Palladium, Platinum or Iridium.
20. Method according to any of the claims 1-19 characterised in that the reduction reaction is performed in a shaft furnace, such as a blast furnace.
21. Method according to any of the claims 1-19 characterised in that the reduction reaction of the metal-oxygen compounds is performed in a fluidised bed, a rotary hearth furnace, a rotary kiln furnace, a cyclone furnace, or a continuous batch-type furnace, to produce directly reduced metal.
22. Method according to any of the claims 1-17 characterised in that the metal-oxygen compounds comprise iron-oxygen-compounds and in that the reduction reaction of the iron-oxygen compounds is performed in a shaft furnace, such as a blast furnace, to produce iron.
23. Method according to any of the claims 1-17 characterised in that the metal-oxygen compounds are iron-oxygen-compounds and in that the reduction process of the iron-oxygen compounds is performed in a fluidised bed, a rotary hearth furnace, a rotary kiln furnace, a cyclone furnace, or a continuous batch-type furnace, to produce directly reduced iron.
24. Method according to any of the preceding claims to produce a substantially solid material comprising a metallic part and a non-metallic part characterised in that the substantially solid material is treated to separate the metallic part from a non-metallic part such as gangue or slag.
25. Method according to claim 24 characterised in that the metallic part is compressed to reduce its porosity.

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26. Method according to claims 24 or 25 characterised in that the metallic part is rolled to form a slab, billet, bloom, rod, section or strip.
27. Method according to any of the claims 24-26 characterised in that the metallic part is extruded to form a profile, section or rod.
28. Method according to any of the claims 24-27 characterised in that the metallic part is formed into a near net shape product.
29. Apparatus for reducing metal-oxygen compounds in a reduction reaction according to the method of any of the claims 1 to 28 characterised in that it comprises a reactor (1), an inlet for the metal-oxygen compounds (2), an inlet for a first metal, an inlet for a gaseous mixture comprising carbon-monoxide (3), optional heating or cooling means to heat or cool different parts of the reactor, an outlet for the gaseous reaction products (4) and an outlet for the substantially solid material resulting from the reduction reaction (5).
30. Apparatus according to claim 29 for reducing metal-oxygen compounds in a reduction reaction according to the method of any of the claims 4 to 28 characterised in that the reactor comprises a first reaction region for generating carbon from the carbon monoxide by the Boudouard reaction and a second reaction region for reducing the metal-oxygen compounds.
31. Apparatus according to claim 29 or 30 characterised in that the reactor also comprises transportation means (6) to transport the solid reactants.
32. Apparatus according to any of the claims 29-31 characterised in that it also comprises means (7) to reintroduce at least part of gaseous reaction products into the process.
33. Apparatus according to any of the claims 29-32 characterised in that it also comprises means (8) to reintroduce at least part of substantially solid material resulting from the reduction reaction into the process.

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34. Apparatus for reducing metal-oxygen compounds according to the method of any of the claims 4 to 28 characterised in that it comprises a reactor which comprises a first reactor part (9) where the generation of carbon from the carbon monoxide by the Boudouard reaction mainly occurs, a second reactor part (10) where the reduction of the metal-oxygen compounds mainly occurs, transport means (11) to transport the solid reactants from the first reactor part (9) to the second reactor part (10), transport means (11) to transport the gaseous mixture comprising carbon-monoxide from the second reactor part (10) to the first reactor part (9), an inlet (2) for the metal-oxygen compounds, an inlet for a first and/or second metal, an inlet (3) for a gaseous mixture comprising carbon-monoxide, heating or cooling means to heat or cool the different parts of the reactor, an outlet (4) for the gaseous reaction products and an outlet (5) for the substantially solid material resulting from the second reduction reaction and optionally means to reintroduce at least part of the gaseous reaction products from outlet (4) into the process through inlet (3), and also optionally means to reintroduce at least part of substantially solid material resulting from the reduction of the metal-oxygen compounds into the process.
35. Apparatus according to any of the claims 29-34 characterised in that the reactor includes a fluidised bed.
36. Apparatus according to any of the claims 29-35 characterised in that the reactor comprises a furnace chosen from the group of furnaces comprising rotary hearth furnaces, rotary kiln furnaces, shaft furnaces, cyclone furnaces, continuous batch-type furnaces.
37. Apparatus according to claim 29-36 characterised in that the reactor is substantially tubular, preferably substantially axi-symmetrical.

**ABSTRACT**

The present invention relates to a method for reducing metal-oxygen compounds in a reduction reaction in which carbon is used as a reducing agent for reducing the metal-oxygen compounds. The invention is characterised in that a first metal is used to aid the reduction reaction. The invention also relates to an apparatus for reducing metal-oxygen compounds according to a method in which carbon is used as a reducing agent for reducing the metal-oxygen compounds and wherein a first metal is used to aid the reduction reaction.

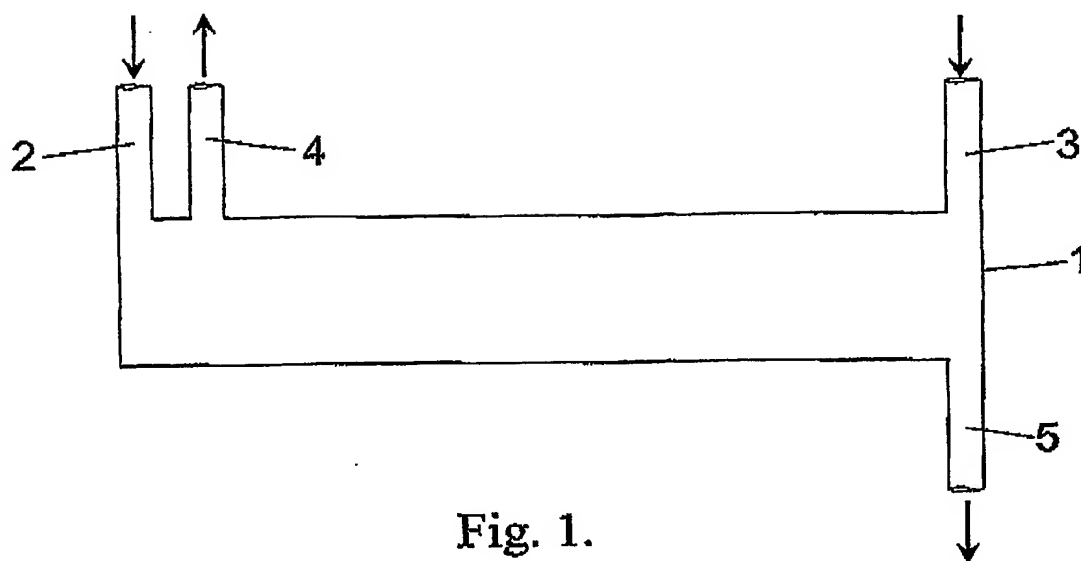


Fig. 1.

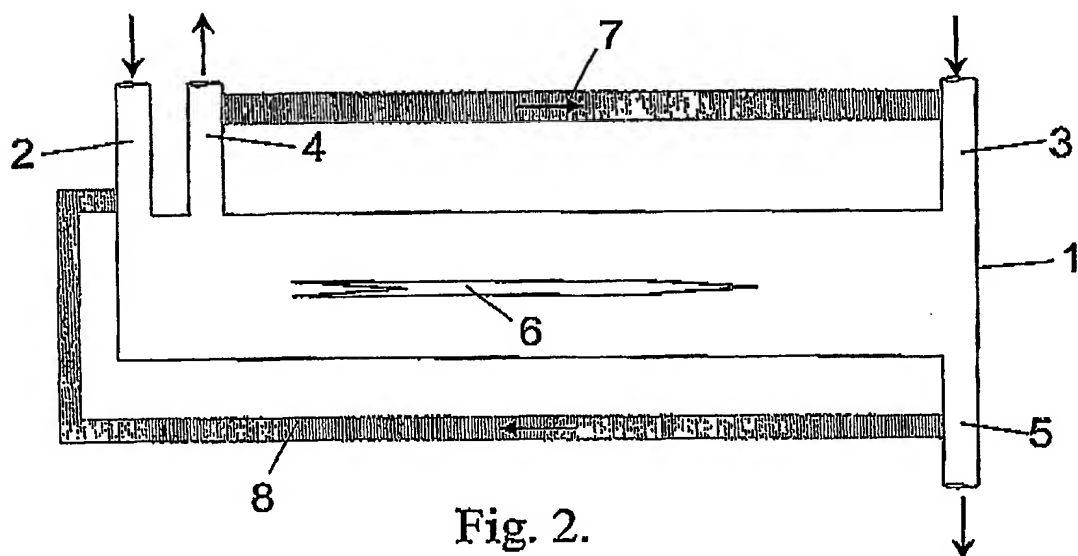


Fig. 2.

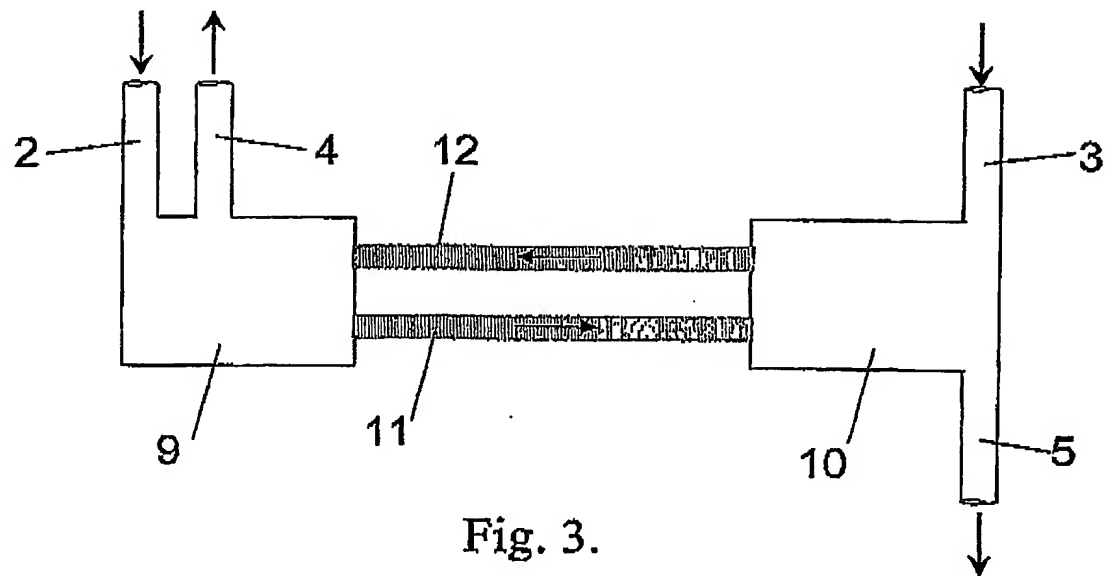


Fig. 3.

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